CHAPTER 630 FLEXIBLE PAVEMENT

Topic 631 - Types of Flexible Pavements & Materials

Index 631.1 Hot Mix Asphalt (HMA)

HMA consists of a mixture of asphalt binder and a graded aggregate ranging from coarse to very fine particles. The aggregate can be treated and the binder can be modified. HMA could be made from new or recycled material. Examples of recycled asphalt include, but is not limited to, hot and cold in-place recycled. HMA is classified by type depending on the specified aggregate quality and mix design criteria appropriate for the project conditions. HMA types are found in the Standard Specifications and Standard Special Provisions.

631.2 Open Graded Friction Course (OGFC)

OGFC is a non-structural wearing course used primarily on HMA. It is occasionally used with modified binders on rigid pavements. The primary benefit of using OGFC is the improvement of wet weather skid resistance, reduced potential for hydroplaning, reduced water splash and spray, and reduced night time wet pavement glare. Secondary benefits include better wet-night visibility of traffic lane stripes and pavement markers, and better wet weather (day and night) delineation between the traveled way and shoulders. OGFC is also known as "open graded asphalt concrete".

For information and applicability of OGFC in new construction and rehabilitation projects refer to OGFC Guideline available on the Department Pavement website. Also, see Maintenance Technical Advisory Guide (MTAG) for additional information and use of OGFC in pavement preservation.

631.3 Rubberized Asphalt Concrete (RAC)

Rubberized asphalt is formulated by mixing granulated (crumb) rubber with hot asphalt to form an elastic binder with less susceptibility to temperature changes. The rubberized asphalt is substituted for the regular asphalt as the binder for the flexible pavement. This is called the wet method. Other methods of using rubber in flexible pavements are available. See Asphalt Rubber Usages Guide (ARUG), available on the Department Pavement website, for further details.

RAC is generally specified to retard reflection cracking, resist thermal stresses created by wide temperature variations and add flexibility to a structural overlay. At present, the Department uses gap-graded (RAC-G) and open-graded (RAC-O) rubberized asphalt. The difference between the two is in the gradation of the aggregate. RAC-O is used only as a non-structural wearing course. RAC-G can be used as either a surface course or a non-structural wearing course. RAC should be considered the strategy of choice when evaluating alternatives for a project. If RAC is found to be inappropriate due to availability, constructibility, environmental factors, or cost, it shall be documented in the scoping document, Project Initiation Document (PID), or Project Report (PR).

The minimum thickness for RAC (any type) should be 0.10 foot for new construction and rehabilitation. For pavement preservation, RAC may be placed as thin as 0.08 foot provided compaction requirements can be met. The maximum thickness for RAC-G is 0.20 foot. The maximum thickness for RAC-O is 0.15 foot. If a thicker surface layer or overlay is called for, then a HMA layer should be placed prior to placing the RAC. RAC should only be placed over a flexible or rigid pavement and not on a granular layer. RAC-O may be placed on top of new RAC-G. Do not place conventional HMA or OGFC over new RAC pavement.

It is undesirable to place RAC-G or RAC-O in areas that will not allow surface water to drain. As an example, a surface that is milled only on the traveled way and not on the shoulder forms a "bathtub" section that can trap water beneath the surface of the traveled way. To prevent this effect, RAC-G should be placed over the whole cross section of the road (traveled way and shoulders).

For additional information and applicability of RAC in new construction and rehabilitation projects refer to Asphalt Rubber Usage Guide available on the Department Pavement website.

631.4 Other Types of Flexible Pavement

There are other types of flexible pavements such as cold mix, Resin Pavement, and Sulphur Extended Asphalt Concrete. The other types of pavements are either used for maintenance treatments or not currently used on State highways. For pavement preservation and other maintenance treatments refer to the Department's Maintenance Manual.

631.5 Stress Absorbing Membrane Interlayers (SAMI)

SAMI's are used as a means for retarding reflective cracks for rehabilitation projects, prevent water intrusion, and in the case of SAMI-R, enhance structural strength. Two types of SAMI are:

- Rubberized (SAMI-R).
- Fabric (SAMI-F), also called Geosynthetic Pavement Interlayer.

Judgment is required when considering the use of SAMI's.

- Consideration should be given to areas that may prohibit surface water from draining out the sides of the overlay, thus forming a "bathtub" section.
- Since SAMI-R can act as a moisture barrier, they should be used with caution in hot environments where they could prevent underlying moisture from evaporating.
- When placed on an existing pavement, preparation is required to prevent excess stress on the membrane. This includes sealing cracks wider than ¼ inch and repairing potholes and localized failures.

A SAMI may be placed between layers of new flexible pavement, such as on a leveling course, or on the surface of an existing flexible pavement. A SAMI-F should not be placed directly on coarse surfaces such as a chip seal, OGFC, areas of numerous rough patches, or on a pavement that has been cold planed. Coarse surfaces may penetrate the fabric and/or the paving asphalt binder used to saturate the fabric may be "lost" in the voids or valleys leaving areas of the fabric dry. For the SAMI-F to be effective in these areas, use a layer of HMA prior to the placement of the SAMI-F.

SAMI-F's have been found to be ineffective:

- When placed under rubberized asphalt concrete. This is due to the high placement temperature of the RAC-G mix, which is close to the melting temperature of the fabric.
- For providing added structural strength when placed in combination with new flexible pavement.
- In the reduction of thermal cracking of the new flexible pavement overlay.

Topic 632-Engineering Criteria

632.1 Engineering Properties

(1) *Smoothness.* The smoothness of a pavement impacts its ride quality, overall durability, and performance. Ride quality (which is measured by the smoothness of ride) is also the highest concern listed in public surveys on pavement condition. Smoothness specifications have been improved and pilot specifications are being evaluated to assure designed smoothness values are achieved in construction. Smoothness specifications should be used where the project meets the warrants for the specification. For up to date and additional information on smoothness and the application of the smoothness specifications see the smoothness page on the Department Pavement website.

(2) *Asphalt Binder Type.* Asphalt binders are most commonly characterized by their physical properties. An asphalt binder's physical properties directly describe how it

will perform as a constituent in HMA pavement. Although asphalt binder viscosity grading is still common, new binder tests and specifications are developed to more accurately characterize asphalt binders for use in HMA pavements. These tests and specifications are specifically designed to address HMA pavement performance parameters such as rutting, fatigue cracking and thermal cracking.

In the past, the Department has classified binder using viscosity grading based on Aged Residue (AR) System. Beginning January 1, 2006, the Department switched to the Performance Graded (PG) System. For polymer-modified binder, the Department continues to use the Performance Based (PBA) binder system.

Performance grading is based on the idea that asphalt binder properties should be related to the conditions under which it is used. PG asphalt binders are selected to meet expected climatic conditions as well as aging considerations with a certain level of reliability. Therefore, the PG system uses a common set of tests to measure physical properties of the binder that can be directly related to field performance of the pavement at extreme temperatures. For example, a binder identified as PG 64-10 must meet performance criteria at an average 7-day maximum pavement temperature of 64°C (147°F) and also at a minimum pavement temperature of –10°C (14°F).

Polymer modified binders are used wherever extra performance and durability are desired. Improvement in resistance to rutting, thermal cracking, fatigue damage, stripping, and temperature susceptibility have led polymer modified binders to be substituted for conventional asphalt in many paving and maintenance applications. For example, polymer modification is used to concurrently meet the requirements for high temperature resistance to rutting and low temperature resistance to thermal cracking.

Table 632.1 provides the binder grade that is to be used for each climatic region for general application. For HMA, values are given for typical and special conditions. For a few select applications such as dikes and tack coats, PG binder requirements are found in the applicable Standard Specifications or Standard Special Provisions.

For locations of each pavement climate region see Topic 615.

Special conditions are defined as those roadways or portion of roadways that need additional attention due to conditions such as:

- Heavy truck/bus traffic (over 10 million ESALs for 20 years).
- Truck/bus stopping areas (parking area, rest area, loading area, etc.).
- Truck/bus stop and go areas (intersections, metered ramps, ramps to and from Truck Scales etc.).
- Truck/bus climbing and descending lanes.

Final decision as to whether a roadway meets the criteria for special conditions rests with the District. It should be noted that whereas special binder grades help meet the flexible pavement requirements for high truck/bus use areas; they should not be considered as the only measure needed to meet these special conditions. The District Materials Engineer (DME) and the District Pavement Advisor should be consulted for additional recommendations for these locations.

For more detailed information on PG binder selection, refer to the Department Pavement website.

632.2 Performance Factors

The procedures and practices found in this chapter are based on research and field experimentation by the Department and AASHTO. They were calibrated for pavement design lives of 10 to 20 years and Traffic Index (TI) ranging from 5.0 to 12. Extrapolations and supplemental requirements were subsequently developed to address longer pavement design lives and higher Traffic Indices. The procedures found in this chapter were based on the mix design and other requirements found in the Standard Specifications and Standard Special Provisions. Alterations to the requirements in these documents can impact the performance of the pavement structure and the performance values found in this chapter.

Topic 633- Engineering Procedures for New and Reconstruction Projects

633.1 Empirical Method

The data needed to engineer a flexible pavement are California R-value of the subgrade and the TI for the pavement design life. Engineering of the flexible pavement is based on a relationship between the gravel equivalent (GE) of the pavement structural materials, the TI, and the California R-value of the underlying material. The relationship was developed by the Department through research and field experimentation.

Gravel equivalency may be defined as the required gravel thickness needed to carry a load compared to a different material's ability to carry the same load. Gravel factor (G_f) is the relative strength of a material to gravel. Gravel factors for the various types of base materials are provided in Table 633.1.

Pavement safety factors are utilized to compensate for construction tolerances allowed by the contract specifications. For pavements that include base and/or subbase, a safety factor of 0.20 foot is added to the GE requirement for the surface layer. Since the safety factor is not intended to increase the GE of the overall pavement, a compensating thickness is subtracted from the subbase layer (or base layer if there is no subbase). For pavements that are full depth asphalt, a safety factor of 0.10 foot is added to the required GE of the flexible pavement. When determining the appropriate safety factor to be added, Hot Mixed Asphalt Base (HMAB) and Asphalt Treated Permeable Base (ATPB) should be considered as part of the surface layer.

The procedures and rules governing flexible pavement engineering are as follows, (Sample calculations are provided on the Department Pavement website.):

(1) *Procedures for Engineering Multiple Layered Flexible Pavement.*

(a) The TI is determined to the nearest 0.5 per Index 613.3, and the California R-value is established per Index 614.3.

(b) The following equation is applied to calculate the gravel equivalent requirement of the entire flexible pavement or each layer:

$$GE = 0.0032(TI)(100 - R)$$

where:

GE = gravel equivalent in feet

TI = Traffic Index

R = California R-value of the material below the layer for which the GE is being calculated.

(c) GE values for each type of material are found in Table 633.1 by layer thickness. The G_f of hot mix asphalt varies with layer thickness (t) for any given TI as follows:

$t \leq 0.50$ ft:	$G_f = \dfrac{5.67}{(TI)^{1/2}}$
$t > 0.50$ ft:	$G_f = (7.00)\dfrac{(t)^{1/3}}{(TI)^{1/2}}$

The equations are valid for TIs ranging from 5 to 15. For TIs greater than 15, use a rigid or composite pavement or contact the Office of Pavement Design (OPD) for experimental options. For TIs less than 5, use a value of TI=5. Table 633.1 sets a limit for placing high HMA thickness with each TI.

(d) The GE to be provided by each type of material in the pavement is determined for each layer, starting with the surface layer and proceeding downward. Apply a safety factor of 0.20 foot to the GE requirement for the surface layer. Since the safety factor is not intended to increase the GE of the overall pavement, a compensating thickness is subtracted from the subbase layer (or base layer if there is

Table 632.1

Asphalt Binder Grade

Binder / Climatic Region	Conventional Asphalt					Rubberized Asphalt	
	Hot Mix Asphalt			Open Graded		Gap Graded	Open Graded
	Typical	Special					
	PG	PG	PBA	PG	PBA(1)	PG	PG
South Coast Central Coast Inland Valley	64-10	70-10	6a(mod)	64-10	6a	64-16	64-16
North Coast	64-16	Use PBA	6a(mod)	64-16	6a	64-16	64-16
Low Mountain South Mountain	64-16	Use PBA	6a(mod)	64-16	6a	64-16	64-16
High Mountain High Desert	64-28	Use PBA	6a, 6b	64-28	6a	58-22	58-22
Desert	70-10	Use PBA	6a(mod), 7	70-10	6a(mod)	64-16	64-16

Note:

(1) For low temperature placement.

no subbase). HMAB and ATPB should be considered as part of the surface layer when applying the safety factor.

(e) The thickness of each material layer is calculated by dividing the GE by the appropriate gravel factor from Table 633.1.

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

Minimum thickness of any asphalt layer should not be less than twice the maximum aggregate size. When selecting the layer thickness, the value is rounded to the nearest 0.05 foot. A value midway between 0.05 foot increments is rounded to the next higher value.

The surface course should have a minimum thickness of 0.15 foot.

Base and subbase materials, other than ATPB, should each have a minimum thickness of 0.35 foot. When the calculated thickness of base or subbase material is less than the desired 0.35 foot minimum thickness, either (a) increase the thickness to the minimum without changing the thickness of the overlying layers or (b) eliminate the layer and increase the thickness of the overlying layers to compensate for the reduction in GE.

Generally, the layer thickness of Lime Treated Subbase (LTS) should be limited, with 0.65 foot as the minimum and 2 feet as the maximum. A surface layer placed directly on the LTS should have a thickness of at least 0.25 foot.

The thicknesses determined by the procedures provided by this equation are not intended to prohibit other combinations and thickness of materials. Adjustments to the thickness of the various materials may be made to accommodate construction restrictions or practices, and minimize costs, provided the minimum thicknesses, maximum thicknesses, and minimum GE requirements (including safety factors), of the subgrade and each layer in the pavement are satisfied.

(2) *Procedures for Full Depth Hot Mix Asphalt.* Full depth hot mix asphalt applies when the pavement structure is comprised entirely of a flexible surface layer in lieu of base and subbase. The flexible surface layer may be comprised of a single or multiple types of flexible pavements including HMA, RAC, interlayers, special asphalt binders, or different mix designs. Considerations regarding worker safety, short construction windows, the amount of area to be paved, or temporary repairs may make it desirable in some instances to reduce the total thickness of the pavement by placing full depth hot mix asphalt. Full depth hot mix asphalt also is less affected by moisture or frost, does not let moisture build up in the subgrade, provides no permeable layers that entrap water, and is a more uniform pavement structure. Use the standard equation in Index 633.1(1) with the California R-value of the subgrade to calculate the initial GE for the entire pavement structure. Increase this by adding the safety factor of 0.10 foot to obtain the required GE for the flexible pavement. Then refer to Table 633.1, select the closest layer thickness for conventional hot mixed asphalt, and determine the adjusted GE that it provides. The GE of the safety factor is not removed in this design. Adjust the final thickness as needed when using other types of materials than hot mixed asphalt.

A Treated Permeable Base (TPB) layer may be placed below full depth hot mix asphalt on widening projects to perpetuate, or match, an existing treated permeable base layer for continuity of drainage. Reduce the GE of the surface layer by the amount of GE provided by the TPB. In no case should the initial GE of the surface layer over the TPB be less than 40 percent of the GE required over the subbase as calculated by the standard engineering equation. When there is no subbase, use 50 for the California R-value for this calculation. In cases where a working table will be used, the GE of the working table is subtracted from the GE of the surface layer as well. A working table is a minimum thickness of material, asphalt, cement, or granular based, used to place construction equipment and achieve compaction requirements when compaction is difficult or impossible to meet.

(3) *Modifications for Pavement Design Life Greater than 20 Years.* The above procedure is based on an empirical method for a twenty-year pavement service life. For pavement design lives greater than twenty-year, in addition to using a TI for that longer service life, provisions should be made to increase material durability and to protect pavement layers from degradation.

The following enhancements shall be incorporated into all flexible pavements with a pavement design life greater than twenty years:

- Use a non-structural wearing course (such as OGFC) above the surface layer (minimum 0.10 foot). See Index 602.1(5) for further details.
- Use rubberized asphalt concrete (maximum 0.20 foot) or a PBA binder (minimum 0.20 foot) for the top of the surface layer.

The following enhancements should be incorporated into all flexible pavements with a pavement design life greater than twenty years when recommended by the District Materials Engineer:

- Use higher asphalt binder content for bottom of the surface layer (rich-bottom concept) and using higher stiffness asphalt binder.
- Utilize subgrade enhancement fabrics at the subgrade for California R-Values less than 40.
- Use SAMIs within the surface layer.
- Use a separation fabric above granular layers. Note that the fabric used needs to be able to resist construction loads or construction equipment must be able to keep off of the fabric.

(4) *Alternate Procedures and Materials.* At times, experimental procedures and/or alternative materials are proposed as part of the design or construction. See Topic 606 for further discussion.

633.2 Mechanistic-Empirical Method

For information on Mechanistic-Empirical Design application and requirements, see Index 606.3.

Topic 634 – Engineering Procedures for Pavement Preservation

For details regarding pavement preservation strategies for flexible pavement, see the Maintenance Technical Advisory Guide on the Department Pavement website.

Topic 635- Engineering Procedures for Pavement and Roadway Rehabilitation

635.1 Empirical Method

(1) *General.* The methods presented in this topic are based on experimental studies for a ten-year pavement design life with interpolations for five and twenty-year pavement design lives. (For pavement design lives greater than twenty years, contact the OPD).

Because there are potential variations in materials and environment that could affect the performance of both the existing pavement and the rehabilitation strategy, it is difficult to develop precise and firm practices and procedures that cover all possibilities for the rehabilitation of pavements. Therefore, the pavement engineer should consult with the District Materials Engineer and other pertinent experts who are familiar with engineering, construction, materials, and maintenance of pavements in the geographical area of the project for additional requirements or limitations than those listed in this manual.

Table 633.1
Gravel Equivalents of Structural Layers (ft)

	HMA(1), (2)											Base and Subbase					
	Traffic Index (TI)																
	5.0 & below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0	14.5 15.0	HMAB; LCB	CTPB; CTB (Cl. A)	ATPB	CTB (Cl. B)	AB	AS
Actual HMA Thickness	G_f (varies with TI and HMA thickness greater than 0.5 ft)											G_f (constant)					
(ft)	2.54	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.46	1.9	1.7	1.4	1.2	1.1	1.0
0.10	0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.16	0.15	0.15	--	--	--	--	--	--
0.15	0.38	0.35	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.22	--	--	--	--	--	--
0.20	0.51	0.46	0.43	0.40	0.38	0.36	0.34	0.33	0.31	0.30	0.29	--	--	--	--	--	--
0.25	0.63	0.58	0.54	0.50	0.47	0.45	0.43	0.41	0.39	0.38	0.37	--	--	0.35	--	--	--
0.30	0.76	0.69	0.64	0.60	0.57	0.54	0.51	0.49	0.47	0.45	0.44	--	--	0.42	--	--	--
0.35	0.89	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.51	0.67	0.60	0.49	0.42	0.39	0.35
0.40	1.01	0.93	0.86	0.80	0.76	0.72	0.68	0.65	0.63	0.61	0.59	0.76	0.68	0.56	0.48	0.44	0.40
0.45	1.14	1.04	0.96	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.66	0.86	0.77	0.63	0.54	0.50	0.45
0.50	1.27	1.16	1.07	1.00	0.94	0.90	0.85	0.82	0.79	0.76	0.73	0.95	0.85	0.70	0.60	0.55	0.50
0.55	1.41	1.29	1.19	1.12	1.05	1.00	0.95	0.91	0.87	0.84	0.81	1.05	0.94	0.77	0.66	0.61	0.55
0.60	1.58	1.45	1.34	1.25	1.18	1.12	1.07	1.02	0.98	0.95	0.91	1.14	1.02	0.84	0.72	0.66	0.60
0.65	1.76	1.61	1.49	1.39	1.31	1.25	1.19	1.14	1.09	1.05	1.02	1.24	1.11	0.91	0.78	0.72	0.65
0.70	--	1.78	1.64	1.54	1.45	1.38	1.31	1.26	1.21	1.16	1.12	1.33	1.19	--	0.84	0.77	0.70
0.75	--	1.95	1.80	1.69	1.59	1.51	1.44	1.38	1.32	1.27	1.23	1.43	1.28	--	0.90	0.83	0.75
0.80	--	2.12	1.96	1.84	1.73	1.64	1.57	1.50	1.44	1.39	1.34	1.52	1.36	--	0.96	0.88	0.80
0.85	--	--	2.13	1.99	1.88	1.78	1.70	1.63	1.56	1.51	1.46	1.62	1.45	--	1.02	0.94	0.85
0.90	--	--	2.30	2.15	2.03	1.92	1.83	1.76	1.69	1.63	1.57	1.71	1.53	--	1.08	0.99	0.90
0.95	--	--	--	2.31	2.18	2.07	1.97	1.89	1.81	1.75	1.69	1.81	1.62	--	1.14	1.05	0.95
1.00	--	--	--	2.47	2.33	2.21	2.11	2.02	1.94	1.87	1.81	1.90	1.70	--	1.20	1.10	1.00
1.05	--	--	--	2.64	2.49	2.36	2.25	2.16	2.07	2.00	1.93	2.00	1.79	--	1.26	1.16	1.05
1.10	--	--	--	--	2.65	2.51	2.40	2.29	2.20	2.12	2.05	--	--	--	--	--	--
1.15	--	--	--	--	2.81	2.67	2.54	2.43	2.34	2.25	2.18	--	--	--	--	--	--
1.20	--	--	--	--	2.98	2.82	2.69	2.58	2.48	2.39	2.30	--	--	--	--	--	--
1.25	--	--	--	--	--	2.98	2.84	2.72	2.61	2.52	2.43	--	--	--	--	--	--
1.30	--	--	--	--	--	3.14	2.99	2.87	2.75	2.65	2.56	--	--	--	--	--	--
1.35	--	--	--	--	--	3.30	3.15	3.01	2.90	2.79	2.70	--	--	--	--	--	--
1.40	--	--	--	--	--	--	3.31	3.16	3.04	2.93	2.83	--	--	--	--	--	--
1.45	--	--	--	--	--	--	3.46	3.32	3.19	3.07	2.97	--	--	--	--	--	--
1.50	--	--	--	--	--	--	3.62	3.47	3.33	3.21	3.10	--	--	--	--	--	--
1.55	--	--	--	--	--	--	--	3.62	3.48	3.36	3.24	--	--	--	--	--	--
1.60	--	--	--	--	--	--	--	3.78	3.63	3.50	3.38	--	--	--	--	--	--
1.65	--	--	--	--	--	--	--	3.94	3.79	3.65	3.52	--	--	--	--	--	--
1.70	--	--	--	--	--	--	--	--	3.94	3.80	3.67	--	--	--	--	--	--
1.75	--	--	--	--	--	--	--	--	4.09	3.95	3.81	--	--	--	--	--	--
1.80	--	--	--	--	--	--	--	--	4.25	4.10	3.96	--	--	--	--	--	--
1.85	--	--	--	--	--	--	--	--	--	4.25	4.10	--	--	--	--	--	--
1.90	--	--	--	--	--	--	--	--	--	4.40	4.25	--	--	--	--	--	--
1.95	--	--	--	--	--	--	--	--	--	4.56	4.40	--	--	--	--	--	--
2.00	--	--	--	--	--	--	--	--	--	--	4.55	--	--	--	--	--	--

Notes:

(1) Open Graded Friction Course (conventional and rubberized) is a non-structural wearing course and provides no structural value.

(2) Top portion of HMA surface layer (maximum 0.20 ft.) may be replaced with equivalent RAC-G thickness. See Topic 631.3 for additional details.

Rehabilitation strategies are divided into three categories:

- Overlay
- Mill and Overlay
- Remove and Replace

Rehabilitation designs are governed by one of the following three criteria:

- Structural adequacy
- Reflective crack retardation
- Ride quality

On resurfacing projects, the entire paved shoulder and traveled way shall be resurfaced. Not only does this help provide a smoother finished surface, it also benefits bicyclists and pedestrians when they are allowed to use the shoulder.

Example calculations are available on the Department Pavement website.

(2) *Data Collection.* Developing a rehabilitation strategy requires collecting background data as well as field data. The Pavement Condition Report (PCR), as-built plans, and traffic information are sources used to prepare rehabilitation strategy recommendations. A thorough field investigation of the pavement surface condition, combined with a current deflection study and coring, knowledge of the subsurface conditions, thicknesses of existing flexible layer, and a review of drainage conditions are all necessary for developing an appropriate rehabilitation strategy.

(3) *Deflection Studies.* Deflection studies along with coring data are used to measure the structural adequacy of the existing pavement. A deflection study is the process of selecting deflection test sections, measuring pavement surface deflection, and calculating statistical deflection values. California Test Method 356 should be followed for deflection studies. A copy of the test method can be obtained and/or downloaded from the Department Pavement website.

To provide reliable rehabilitation strategies, it is recommended that this process be done no more than 18 months prior to construction start.

a) Test Sections:

Test sections are portions of a roadway considered to be representative of roadway conditions being studied for rehabilitation. California Test Method 356 provides information on selecting test sections and different testing devices. Test sections should be determined in the field based on safe operation and true representation of pavement sections. Test sections can be determined either by the test operator or by the pavement engineer in the field.

Occasionally, a return to a project site may be required for additional testing after reviewing the initial deflection data in the office.

Individual deflection readings for each test section should be reviewed prior to determining statistical values. This review may locate possible areas that are not representative of the entire test section. An example would be a localized failure with a very high deflection. It may be more cost effective to repair the various failed sections prior to rehabilitation. Thus, the high deflection values in the repaired areas would not be included when calculating statistical values for the representative test sections.

b) Mean and 80th Percentile Deflections:

The mean deflection level for a test section is determined by dividing the sum of individual deflection measurements by the number of the deflections:

$$\bar{x} = \frac{\Sigma D_i}{n}$$

where:

$\bar{x}$ = mean deflection for a test section, in inches

D_i = an individual measured surface deflection in the test section, in inches

n = number of measurements in the test section

The 80th percentile deflection value represents a deflection level at which approximately 80 percent of all deflections are less than the calculated value and 20 percent are greater than the value. Therefore, a strategy based on 80th percentile deflection will provide thicker rehabilitation than using the mean value.

For simplicity, a normal distribution has been used to find the 80th percentile deflection using the following equation:

$$D_{80} = \bar{x} + 0.84s$$

where:

D_{80} = 80th percentile of the measured surface deflections for a test section, in inches

s = standard deviation of all test points for a test section, in inches

$$s = \sqrt{\frac{\sum\left(D_i - \bar{x}\right)^2}{n-1}}$$

D_{80} is typically calculated as part of the deflection study done by the test operator. The pavement engineer should verify that the D_{80} results provided by the operator are accurate.

c) Grouping:

Adjacent test sections may be grouped and analyzed together. There may be one or several groups within the project.

A group is a collection of test sections that have similar engineering parameters. Test sections can be grouped if they have all of the following conditions:

- Average D_{80} that vary less than 0.01 inch.
- Average existing hot mix asphalt thickness that vary less than 0.10 foot.
- Similar base material.
- Similar TI

Once groups have been identified, D_{80} and existing surface layer thickness of each group can be found by averaging the respective values of test sections within that group.

An alternative to the grouping method outlined above is to analyze each test section individually and then group them based on the results of analysis. This way, all the test sections that have similar rehabilitation strategies would fall into the same group.

(4) *Procedures for Rigid Pavement Overlay on Existing Flexible Pavement (Concrete Overlay).* For concrete overlay (sometimes referred to as Whitetopping) strategies, only structural adequacy needs to be addressed. To address structural adequacy, use the tables in Index 623.1 to determine the thickness of the rigid layer. The overlay should be thick enough to be considered a structural layer. Therefore, thin or ultra thin concrete layers (< 0.65 foot) are not qualified as concrete overlay. To provide a smooth and level grade for the rigid surface layer, place a 0.10 foot to 0.15 foot HMA on top of the existing flexible layer.

(5) *Overlay Procedures for Flexible over Existing Flexible Pavement.*

a) Structural Adequacy. Pavement condition, thickness of surface layer together with measured deflections and the projected TI provide the majority of the information to be used for determining structural adequacy. Structural adequacy is determined using the following procedures and rules:

1) Determine the Tolerable Deflection at the Surface (TDS). The term “Tolerable Deflection” refers to the level beyond which repeated deflections of that magnitude produce fatigue failure prior to the planned TI. Tolerable Deflection is obtained from Table 635.1A knowing the existing flexible pavement thickness and TI. For existing flexible pavement over a treated base, use TI and the TDS values

in the row for Treated Base (TB) found in Table 635.1A

The existing base is considered treated if it meets all of the following conditions:

- Its depth is equal to or greater than 0.35 foot.
- The D_{80} is less than 0.015 inch.
- It is rigid pavement, Lean Concrete Base (LCB), or Class A Cement Treated Base (CTB-A)

2) For each group compare the TDS to the average D_{80}. If the average D_{80} is smaller than the TDS, then the existing pavement is structurally adequate and no overlay is needed to meet this requirement.

If the average D_{80} is greater than the TDS, determine the required percent reduction in deflection at the surface (PRD) to restore structural adequacy as follows:

$$\text{PRD} = \frac{AverageD_{80} - TDS}{AverageD_{80}}(100)$$

where:

PRD = percent reduction in deflection required at the surface, as percent

TDS = tolerable deflection at the surface, in inches

Average D_{80} = mean of 80th percentile of the deflections for each group, in inches

3) Determine the additional GE required using the calculated PRD and Table 635.1B. The additional GE is the amount of aggregate subbase (AS) that will provide sufficient strength to reduce the deflections to less than the tolerable level.

4) Determine the required overlay thickness by dividing GE by G_f (see equation below.)

$$\text{Thickness (t)} = \frac{\text{GE}}{G_f}$$

Commonly used G_f for rehabilitation purposes are presented in Table 635.1C.

b) Reflective Cracking. The goal of these procedures is to keep existing pavement cracks from propagating to the surface during the pavement design life. Retarding the propagation of cracks from the existing pavement is required component in engineering overlays. The procedures and rules for engineering for reflective cracking are as follows:

1) Determine the minimum thickness required for a 10-year pavement design life. For flexible pavements over untreated bases, the minimum thickness of a HMA overlay with a ten-year design life should be half the thickness of the existing flexible pavement up to 0.35 foot.

For flexible pavements over treated bases (as defined in the previous section on structural adequacy), minimum HMA overlay of 0.35 foot should be used for a ten-year design life.

Exception: when the underlying material is a thick rigid layer (0.65 foot or more) such as an overlaid jointed plain concrete pavement that was not cracked and seated, a minimum thickness of 0.45 foot should be used.

2) Adjust thickness if the pavement design life is different than 10 years. For a five-year design life, experience has determined the thickness should be 75 percent of the ten-year thickness for reflective cracking. For a twenty-year design life, use 125 percent.

Table 635.1A
Tolerable Deflections
in (0.001 inches)

Exist. HMA thick (ft)	Traffic Index (TI)											
	5	6	7	8	9	10	11	12	13	14	15	16
0.00	66	51	41	34	29	25	22	19	17	15	14	13
0.05	61	47	38	31	27	23	20	18	16	14	13	12
0.10	57	44	35	29	25	21	19	16	15	13	12	11
0.15	53	41	33	27	23	20	17	15	14	12	11	10
0.20	49	38	31	25	21	18	16	14	13	12	10	10
0.25	46	35	28	24	20	17	15	13	12	11	10	9
0.30	43	33	27	22	19	16	14	12	11	10	9	8
0.35	40	31	25	20	17	15	13	12	10	9	8	8
0.40	37	29	23	19	16	14	12	11	10	9	8	7
0.45	35	27	21	18	15	13	11	10	9	8	7	7
0.50 (1)	32	25	20	17	14	12	11	9	8	8	7	6
TB (2)	27	21	17	14	12	10	9	8	7	6	6	5
	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
0.00	58	45	37	31	27	23	20	18	16	15	13	12
0.05	53	42	34	29	25	21	19	17	15	14	12	11
0.10	50	39	32	27	23	20	18	16	14	13	11	11
0.15	46	36	30	25	21	19	16	14	13	12	11	10
0.20	43	34	28	23	20	17	15	14	12	11	10	9
0.25	40	32	26	22	19	16	14	13	11	10	9	8
0.30	37	29	24	20	17	15	13	12	11	9	9	8
0.35	35	27	22	19	16	14	12	11	10	9	8	7
0.40	32	26	21	18	15	13	11	10	9	8	8	7
0.45	30	24	20	16	14	12	11	9	9	8	7	6
0.50 (1)	28	22	18	15	13	11	10	9	8	7	7	6
TB (2)	24	19	15	13	11	10	8	7	7	6	5	5

Notes:

(1) For an HMA thickness greater than 0.50 ft use the 0.50 ft depth.

(2) Use the TB line to represent treated base materials, regardless of the thickness of HMA cover.

Adjust overlay thickness for alternative materials.

A thickness equivalency of not more than 1:2 is given to the RAC-G when compared to the HMA for reflective crack retardation. The equivalencies are tabulated in Tables 635.1D.

If a SAMI-R is placed under a non-rubberized asphalt concrete that is engineered for reflective crack retardation, the equivalence of a SAMI-R depends upon the type of base material under the existing pavement. When the base is a treated material, a SAMI-R placed under HMA or OGFC is considered to be equivalent to 0.10 foot of HMA. When the base is an untreated material SAMI-R is equivalent to 0.15 foot of HMA.

A SAMI-F placed under HMA that is engineered for reflective crack retardation provides the equivalent of 0.10 foot of HMA. This allows the engineer to decrease the new profile grade and also save on flexible pavement materials.

Table 635.1C

Commonly Used G_f for Asphaltic Layers in Rehabilitation

Material	G_f (1)
Hot Mix Asphalt Overlay	1.9
Hot Recycled Asphalt	1.9
Cold in-Place Recycled Asphalt	1.5
HMA Below the Analytical Depth (2)	1.4

Notes:

(1) For G_f of bases and subbasses see Table 663.1B

(2) Analytical depth is defined in 635.1(b).

Wearing courses are not included in the thickness for reflective cracking.

Thicker sections may be warranted. Factors to be considered that might necessitate a thicker overlay are:

- Type, sizes, and amounts of surface cracks.
- Extent of localized failures.
- Existing performance material and age.
- Thickness and performance of previous rehabilitation.
- Environmental factors.
- Anticipated future traffic loads (Traffic Index).

As always, good engineering judgment will be necessary for final decisions. Final decision for when to use more than the minimum requirements found in this manual rests with the District.

c) Ride Quality. Ride quality is evaluated based on the pavement's smoothness. The Department records smoothness as part of Pavement Condition Survey using the International Roughness Index (IRI). According to FHWA, the IRI value that most motorists consider uncomfortable for flexible pavement is 170 inches per mile. When IRI measurements are 170 inches per mile or greater, the engineer must address ride quality.

To improve ride quality, place a hot mix asphalt overlay thick enough (0.25 foot minimum) to be placed in two lifts. RAC-G may be placed in two 0.10 foot lifts to meet the ride quality requirement. However, if a 0.10 foot layer cools prior to compaction, this strategy is inappropriate. A wearing course may be included in the ride quality thickness. SAMI's do not have any effect on ride quality.

Ride quality will ultimately govern the rehabilitation strategy if the requirements for structural adequacy and reflective crack retardation are less than 0.25 foot.

Table 635.1B

Gravel Equivalence Needed for Deflection Reduction

Percent Reduction In Deflection	GE in Feet For HMA Overlay Design	Percent Reduction In Deflection	GE in Feet For HMA Overlay Design
5	0.02	46	0.55
6	0.02	47	0.57
7	0.02	48	0.59
8	0.02	49	0.61
9	0.03	50	0.63
10	0.03	51	0.66
11	0.04	52	0.68
12	0.05	53	0.70
13	0.05	54	0.72
14	0.06	55	0.74
15	0.07	56	0.76
16	0.08	57	0.79
17	0.09	58	0.81
18	0.09	59	0.83
19	0.10	60	0.85
20	0.11	61	0.87
21	0.12	62	0.89
22	0.14	63	0.91
23	0.15	64	0.94
24	0.16	65	0.96
25	0.18	66	0.98
26	0.19	67	1.00
27	0.20	68	1.02
28	0.21	69	1.04
29	0.23	70	1.06
30	0.24	71	1.09
31	0.26	72	1.11
32	0.28	73	1.13
33	0.29	74	1.15
34	0.31	75	1.17
35	0.33	76	1.19
36	0.35	77	1.22
37	0.37	78	1.24
38	0.38	79	1.26
39	0.40	80	1.28
40	0.42	81	1.30
41	0.44	82	1.32
42	0.46	83	1.34
43	0.48	84	1.37
44	0.51	85	1.39
45	0.53	86	1.41

Please note that the Standard Specification gives the Contractor the option to place 0.25 foot in one layer. Any pavement recommendations that are based on improving ride quality should note that the overlay needs to be placed in two lifts and specified as such in the project Special Provisions.

(6) *Mill and Overlay Procedures.* Mill and Overlay is the removal of part of the surface layer and then placing an overlay. Since existing pavement thicknesses will have slight variations, to ensure the milling machine does not loosen the base material (and contaminate the recycled mix in a recycling case), the procedure should have at least the bottom 0.15 foot of the existing surface layer. If removal of the surface layer and any portion of the base are required, use the procedures for Remove and Replace in Index 635.1(7).

a) Structural Adequacy. When engineering the structural adequacy for Mill and Overlay, the TDS is determined by using the thickness of the existing pavement prior to milling.

The Engineer must first consider milling down to no more than the "analytical depth". The "analytical depth," as defined by the Department, is the milled depth at which the calculation switches from an algorithm in which the GE required to replace the milled material is obtained by increasing the surface deflection by 12 percent for each 0.10 foot milled, to an algorithm in which the GE required to replace the milled material is obtained by replacing a material of lower gravel factor. The analytical depth is the least of:

- The depth where the Percent Reduction in deflection required at the Milled depth (PRM) reaches 70 percent.
- The milled depth reaches 0.50 foot.
- The bottom of the existing HMA layer.

Table 635.1D

Reflective Crack Retardation Equivalencies (Thickness in ft)

HMA	RAC-G	RAC-G over SAMI-R
0.15	0.10	
0.20	0.10	
0.25	0.15	
0.30	0.15	
0.35[1]	• 0.15 if crack width < 1/8 inch • 0.20 if crack width ≥ 1/8 inch or underlying material CTB, LCB, or rigid pavement	• N/A for crack width < 1/8 inch • 0.10 if crack width ≥ 1/8 inch and underlying material untreated • 0.15 if crack width ≥ 1/8 inch and underlying material CTB, LCB, or rigid pavement

Note:

(1) A HMA thickness of 0.35 foot is usually the maximum thickness recommended by the Department for reflection crack retardation on flexible pavements.

The percent reduction in deflection at the milled depth is based on a research study that determined deflections increase by 12 percent for each additional 0.10 foot of milled depth. Since it is not known at what milled depth the 70 percent PRM level or analytical depth will be reached, an iterative type of calculation is required.

Using the thickness of the existing HMA layer, the TI, and base material, determine the TDS from Table 635.1A. The deflection at the milled depth is found from the equation:

$$DM = D_{80} + \left[(12\%) \left(\frac{MillDepth}{0.10\ ft} \right) (D_{80}) \right]$$

where

D_{80} = 80th Percentile deflections, in inches.

Mill Depth = the depth of the milling in feet.

DM = the calculated deflection at the milled depth in inches.

Then:

$$PRM = \left(\frac{DM - TDS}{DM} \right) (100)$$

where

PRM = percent reduction in deflection required at the milled depth.

Utilizing the calculated PRM value, go to Table 635.1B to get the total GE required to be placed on top of the milled pavement surface. Since deflections are calculated at the milled depth, the total GE required to reduce the measured deflection to the tolerable level is a combination of:

- The GE determined from the Overlay calculations
- The GE required to replace the material removed by the milling process.

If milled material is to be replaced by HMA or Hot Recycled Asphalt (HRA), the overlay thickness is found by dividing the GE by the G_f of HMA or HRA.

For Cold In-Placed Recycled Asphalt (CIPRA), the surface of the CIPRA material has a low resistance to abrasion. Therefore, all CIPRA material must be covered with a wearing surface shortly after the recycling process. If the cap layer is an OGFC layer, its thickness should not be considered in the design. For a HMA cap, using the total GE requirement and subtracting the GE of the CIPRA thickness, the thickness of the HMA cap is determined. It is recommended to round up to get the CIPRA and HMA thicknesses.

GE of HMA = (Total GE required) – (CIPRA thickness)(G_f of CIPRA)

Thickness of HMA = GE of HMA/ (G_f of HMA)

For other overlay materials, use either the respective G_f or the equivalency ratio. For G_f values of material refer to Table 635.1C.

If the milling goes below the analytical depth, the analysis changes. The existing material below the analytical depth is considered to be of questionable structural integrity and hence assigned the G_f of 1.4. The additional GE that is required to replace the portion below analytical depth is calculated by multiplying the G_f of 1.4 by the milled depth below the analytical depth.

Additional GE = [(1.4)(milled depth below the analytical depth)]

This is added to the required GE to be placed on top of the milled surface at the analytical depth. The rest is the same as before.

(b) Reflective Cracking. The minimum thickness for reflective cracking is determined using the same procedures used for reflective cracking for overlays found in Index 635.1(5)(b) except that the thickness is determined based on the remaining surface layer rather than the initial surface layer.

(c) Ride Quality. Since mill and overlay uses two procedures, it is considered sufficient to smooth a rough pavement.

(7) *Remove and Replace.* The Remove and Replace operation consists of removing the entire surface layer and part or all of the base

and subbase material. The entire removed depth is then replaced with a new flexible or rigid pavement structure. The Remove and Replace strategy is most often used when:

- It is not possible to maintain the existing profile grade using Mill and Overlay.
- Existing base and or subbase material is failing and needs to be replaced.
- It is the most cost effective strategy based on life cycle cost analysis.

Remove and Replace covers a variety of strategies. The discussion found here provides some general rules and minimum requirements for Remove and Replace strategies in general. For more specific information see the technical guidance on the Department Pavement website.

Because the existing surface layer is removed only structural adequacy needs to be addressed for Remove and Replace.

a) Partial depth removal. When only a portion of the existing depth is being removed, consideration needs to be given to the strength of the remaining pavement structure. Because the pavement has been stressed and has been subject to contamination from fines and other materials over time, it does not have the same strength (GE) as new material. Currently, for partial depth removals, the most effective engineering method is to determine the theoretical deflection of the remaining material otherwise known as PRM. It should be noted that the greater the depth of removal, the less accurate the determination might be of the calculated deflections.

   Also, using deflections for Remove and Replace strategies is also less accurate if a bulldozer or a scraper is used to remove the material under the pavement instead of a milling machine. This method of removing material disturbs the integrity of the in-place material from which the deflections were measured.

   Because of these issues, the DME may require reduced GE from what is found in this manual or additional pavement thickness. Final determination of what GE is used rests with the District.

   It is recommended that if the removal depth is more than 1 foot, determine the pavement thickness and layers use the method for new or reconstructed pavements discussed in Index 633.1. If the pavement structure is being replaced with rigid pavement, the resulting total pavement structure (including existing pavement left in place) cannot be less than the minimum values found in the rigid pavement catalog in Topic 623.

   The analysis used for partial depth Remove and Replace with flexible pavement is similar to the Mill and Overlay analysis. The procedures are as follows:

   1) Consider milling down to what is called the analytical depth. This is an iterative type of calculation since it is not known at what milling depth the analytical depth will be reached.
   2) Use the thickness of the existing HMA layer, the design TI and base material in Table 635.1A to determine the TDS. Then find the DM knowing D_{80} and the mill depth. Use DM and TDS to find the percent reduction in deflection at the milled depth (PRM).
   3) Utilizing this calculated PRM value go to Table 635.1B to obtain the GE required to be placed on top of the milled surface. When the milled depth reaches the analytical depth, the analysis changes. The GE for the material milled below the analytical depth is added to the GE required at the analytical depth. The GE for each layer is calculated by multiplying G_f by the thickness of the layer milled.
   4) Determine the required minimum thickness of HMA needed by dividing the sum of the GE's by the G_f of the new HMA (see equation below.)

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

For the Remove and Replace method, use the G_f for the new HMA commensurate with the TI and HMA thickness found in Table 633.1. The total HMA thickness can be solved for each 0.05 foot of material milled until the desired profile is reached. Round the replacement thickness to the nearest 0.05 foot.

5) Adjust thicknesses as needed for alternate materials.

b) Full depth removal. When material is removed all the way to the subgrade, the Remove and Replace strategy should be engineered using the same procedures used for new construction found in Index 633.1.

(8) *Preparation of Existing Pavement.* <u>Existing pavement distresses should be repaired before overlaying the pavement.</u> Cracks wider than ¼ inch should be sealed; loose pavement removed/replaced; and potholes and localized failures repaired. Routing cracks before applying crack sealant has been found to be beneficial. The width of the routing should be ¼ inch wider than the crack width. The depth should be equal to the width of the routing plus ¼ inch. In order to alleviate the potential bump in the overlay from the crack sealant, leave the crack sealant ¼ inch below grade to allow for expansion (i.e. recess fill). The Materials Report should include a reminder of these preparations. Additional discussion of repairing existing pavement can be found on the Department Pavement website.

(9) *Choosing the Rehabilitation Strategy.* The final strategy should be chosen based on pavement life-cycle cost analysis (LCCA). The strategy should also meet other considerations such as constructibility, maintenance, and the other requirements found in Chapter 610.

635.2 Mechanistic-Empirical Method

For information on Mechanistic-Empirical Design application and requirements, see Index 606.3.

Topic 636 –Other Considerations

636.1 Traveled Way

(1) *Mainline.* No additional considerations.

(2) *Ramps and Connectors.* Rigid pavement should be considered for freeway-to-freeway connectors and ramps near major commercial or industrial areas (TI > 14.0), truck terminals, and all truck weighing and inspection facilities.

(3) *Ramp Termini.* Distress is compounded on flexible pavement ramp termini by the dissolving action of oil drippings combined with the braking of trucks. Separate pavement strategies should be developed for these ramps that may include thicker pavement structures, special asphalt binders, aggregate sizes, or mix designs. Rigid pavement should be considered for exit ramp termini where there is a potential for shoving or rutting. At a minimum, rigid pavement should be used for exit ramp termini of flexible pavement ramps where a significant volume of trucks is anticipated (TI > 12.0). For the engineering of rigid pavement ramp termini, see Index 626.1(3).

636.2 Shoulders

The TI for shoulders is given in Index 613.5(2). See Index 1003.6(2) for surface quality guidance for highways open to bicyclists.

636.3 Intersections

Where intersections have stop control or traffic signals, special attention is needed to the engineering of flexible pavements to minimize shoving and rutting of the surface caused by trucks braking. Separate pavement strategies should be developed for these intersections that may include thicker pavement structures, special asphalt binders, aggregate sizes, or mix designs. Rigid pavement is another alternative for these locations. For additional information see Index 626.3. For further assistance on this subject, contact your District Materials Engineer, METS, Office of Flexible Pavement Materials, or Division of Design, OPD.

636.4 Roadside Facilities

(1) *Safety Roadside Rest Areas.* Safety factors for the empirical method should be applied to the ramp pavement but not for the other areas.

For truck parking areas, where pavement will be subjected to truck starting/stopping and oil drippings which can soften asphalt binders, separate flexible pavement structures which may include thicker structural sections, alternative asphalt binders, aggregate sizes, or mix designs should be considered. Rigid pavement should also be considered.

(2) *Park & Ride Facilities.* To engineer a park and ride facility based on the standard traffic projections is not practicable because of the unpredictability of traffic. Therefore, standard structures, based on anticipated typical load, have been adopted. However, if project site-specific traffic information is available, it should be used with the standard engineering procedures.

The layer thicknesses shown in Table 636.4 are based on previous practices. These pavement structures are minimal, but are considered adequate since additional flexible surfacing can be added later, if needed, without the exposure to traffic or traffic-handling problems typically encountered on a roadway.

(3) *Bus pads.* Use rigid or composite pavement strategies for bus pads.

Table 636.4
Pavement Structures for Park and Ride Facilities

California R-value Subgrade	Thickness of Layers	
	HMA[1] (ft)	AB (ft)
< 40	0.25	0
	0.15	0.35
≥ 40	0.15	0
≥ 60	Penetration Treatment[2]	

Notes:
(1) Place in one lift.
(2) Penetration Treatment is the application of a liquid asphalt or dust palliative on compacted roadbed material. See Standard Specifications.

Topic 637- Engineering Analysis Software

Computer programs for engineering flexible pavements using the procedures in this chapter can be found on the Department Pavement website. These programs employ the procedures and requirements for flexible pavement engineering enabling the engineer to compare numerous combinations of materials in seeking the most cost effective pavement structure.